



TAKEN BY STORM

How Heavy Rain is Worsening
Algal Blooms in Lake Erie

WITH A FOCUS ON THE MAUMEE RIVER IN OHIO

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With a Focus on the Maumee River in Ohio

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EXECUTIVE SUMMARY

Lake Erie is a vital resource for the Great Lakes region and the nation at large, providing a home to thousands of wildlife species, drinking water for millions of people, and a billion-dollar fishing industry. At the same time, Lake Erie is extremely vulnerable. Since the late 1990s, Harmful Algal Blooms (HABs) have returned to the lake in force. *Microcystis* algae, which produce the toxin microcystin, have captured the attention of scientists, public health officials, and environmental advocates alike. There is widespread agreement that HABs are one of the most significant problems facing the people and wildlife of Lake Erie today.

Record-breaking rains—and droughts—are affecting the size of these toxic blooms. Why? Rain causes runoff of nonpoint source pollutants such as excess fertilizer and livestock waste, which cause an upsurge in lake nutrient levels and promote the growth of HABs. Unfortunately, the changing global climate is bringing both extreme rainfall and significant drought to the Great Lakes region. These pendulum swings, which cause many industries to suffer, are contributing to record-breaking HABs.

As a follow-up to the National Wildlife Federation's 2011 report *Feast and Famine in the Great Lakes: How Nutrients and Invasive Species Interact to Overwhelm the Coasts and Starve Offshore Waters*, this report examines this relationship between large rain events, nutrient runoff, and HAB size, focusing on the input from Maumee River in Ohio.

Lake Erie's HAB problem is multifaceted. It is influenced by changing lake ecology from aquatic invasive zebra and quagga mussels and by warming temperatures. It is also influenced by point and nonpoint sources of pollution, including agriculture, sewage, dredging, and open-lake disposal.¹ These contribute to phosphorus loads, specifically dissolved reactive phosphorus (DRP), which spurs HAB growth. In recent years, point sources of phosphorus are declining due to regulation; therefore unregulated nonpoint source pollution is emerging as the predominant source of phosphorus. Nonpoint sources provided more than 60 percent of phosphorus to Lake Erie between 1998 and 2005.² Excess DRP from agriculture—a nonpoint source—is particularly conducive to HAB growth.

The Lake Erie basin boasts the largest percentage of agricultural land in the Great Lakes region. Several tributaries carry phosphorus from surrounding farmland into Lake Erie. The Detroit and Sandusky Rivers are also contributors. Although all tributaries warrant attention, the Maumee River is a surrogate example for other watersheds. The Maumee River Valley, located west of Lake Erie and spanning Ohio, Michigan, and Indiana, is the largest tributary to Lake Erie by area. Though dissolved reactive phosphorus loads are increasing in all of the watersheds, observed DRP loads into Lake Erie from the Maumee River have increased 218 percent since 1995.³

Combine excessive nutrients with heavy rains, and the result is record-breaking HABs. The reason: rain causes runoff from farmland and transports nutrients from fertilizer and animal waste into Lake Erie's western basin. More rain storms, and particularly more heavy rain storms, carry more nutrients, particularly phosphorous, into the lake. Soluble phosphorus in the form of DRP presents an opportunity for algae to grow—and, in these cases, the algal blooms become toxic.

The following storm snapshots showcase eight seasons⁴ of rainfall over the Maumee River Valley, consequent phosphorus loads, and HABs in Lake Erie.⁵ Four of these seasons experienced record-break-

FIGURE 1.
Rain Contribution to
Harmful Algal Blooms



ing rains (1998, 2003, 2008, 2011), and three experienced significant drought (1999, 2001, 2012), while one is a moderately wet season (2002). This report does not try to prove a direct 1:1:1 correlation between rainfall, phosphorus loads, and HAB size, rather it does show that rainfall is the master driver of dissolved reactive phosphorus (DRP) loads in these specific cases. Information in this report highlights a need to account for changes in weather and climate, especially with regards to rainfall amounts, when combating the complex problem of Lake Erie's HABs.

FIGURE 2.
Summary of Storm
Snapshot Years,
Dissolved Reactive
Phosphorus (DRP)
Loads at Waterville, OH⁶
and Harmful Algal
Bloom Size⁷

YEAR	WET OR DRY SEASON	DETAILS OF RAIN & BLOOM
1998	Wet	<ul style="list-style-type: none"> • Second wettest June for Ohio since 1883, 10 inches of rain in a single storm • 515 metric tons of DRP • By October a HAB was reported, size estimates are close to 2003's bloom
1999	Dry	<ul style="list-style-type: none"> • Drought conditions over northwest Ohio for spring and summer months • 215 metric tons of DRP • Federal agricultural disaster declarations for drought in Maumee River Valley counties • Bloom size negligible
2001	Dry	<ul style="list-style-type: none"> • Precipitation statewide remained below normal for the calendar year of 2001 • 260 metric tons of DRP • Bloom size negligible
2002	Moderate	<ul style="list-style-type: none"> • Wet winter and spring, followed by dry summer • 440 metric tons of DRP • Bloom size 65 square miles
2003	Wet	<ul style="list-style-type: none"> • Maumee region's third wettest May in over 100 years • 570 metric tons of DRP • Peak bloom covered 272 square miles
2008	Wet	<ul style="list-style-type: none"> • Over 1100 daily precipitation records were broken in Ohio • 840 metric tons of DRP • Bloom covered 400 square miles
2011	Wet	<ul style="list-style-type: none"> • 75 percent of normal annual precipitation for Ohio fell in the four months between February and May • 560 metric tons of DRP • Wettest spring on record for Ohio • 2,000 square miles of bloom in Lake Erie—3.3 times greater than the peak intensity of the 2008 bloom
2012	Dry	<ul style="list-style-type: none"> • Moderate drought for part of spring and between a Severe and Extreme drought all of the summer • Significantly smaller loads of dissolved reactive phosphorus reported • microcystin concentration stayed in the "low risk" category • Scientists are currently working on measuring and reporting the total size of bloom

Climate change is causing the Midwest/Great Lakes region to experience warmer air temperatures and large rainfall events—along with swings of drought. Heavy precipitation events are particularly on the rise. Since 1958, days with very heavy precipitation have increased by 31 percent.¹⁰ Additionally, the seasons are changing. Warm conditions in the late winter or early spring can cause rain on snow events,¹¹ expanding the time period of runoff potential. Although we identify a few storm snapshots in this report, the wettest spring on record for Ohio produced a memorably massive HAB in 2011.¹² This is an alarming snapshot of disaster to Lake Erie if record-breaking rains and excess nutrient loads continue. Scientists recently ran climate scenario models that show larger rain events of rainfall amounts of about 1.2 inches, have the potential to be twice as frequent over western Lake Erie basin.¹³

In order to prepare for heavier rain events we need to reconsider some agricultural practices and policies. More innovative policies and programs, combined with more outreach to land managers, farmers, and agricultural retail-

ers will help ensure that heavy storms do not exacerbate Lake Erie's existing vulnerability to phosphorus loading and HABs. Better practices will also reduce unintended expenses from fertilizer applications being washed away.

Some principal recommendations are as follows (more details are outlined in Conclusion and Recommendations):



Agricultural Practices

- Identify Best Management Practices (BMPs) that fit climate and weather trends by reducing phosphorus levels on the soil surface. Until recently, conservation tillage was thought to be a standard best management practice as it has great benefits toward preventing erosion. However, conservation tillage combined with heavy fertilizer application leaves high concentrations of phosphorus in the upper soil, making it susceptible to wash into lakes and streams with rain runoff.
 - > When applying conservation tillage, ensure that fertilizer gets below the surface and is absorbed well to avoid losses through tiles.
 - > A promising BMP approach that accounts for heavier rain is the use of cover crops¹⁴, as they diminish nutrient reduction from runoff and reduce overall erosion. Cover crops also help wildlife, since they increase nesting areas for species such as ducks, and provide high quality food sources for many grassland and game bird species.¹⁵
- Consider timing of nutrient application. Do not apply nutrient fertilizers if the weather forecast calls for a greater than 50 percent chance of heavy rain. Avoid application on frozen ground.
 - > Promote the message of proper timing for fertilizer application and provide technical assistance through the local Certified Crop Advisors (CCA) and agriculture retailers.
 - > Promote implementation of voluntary nutrient reduction programs, such as the 4R (Right source, Right rate, Right time, Right place) Program.
- Develop partnerships between farmers, land managers, and Certified Crop Advisors (CCAs) and respective state climatologists and/or the Great Lakes Integrated Sciences and Assessment Center (GLISA). These scientists have access to decades of historical records and the climate model expertise to give seasonal or longer-term rainfall forecasts, useful for adjusting nutrient application practices.
- Replace agricultural drainage ditches with treatment wetlands wherever possible. This will also help combat erosion caused by severe storms.

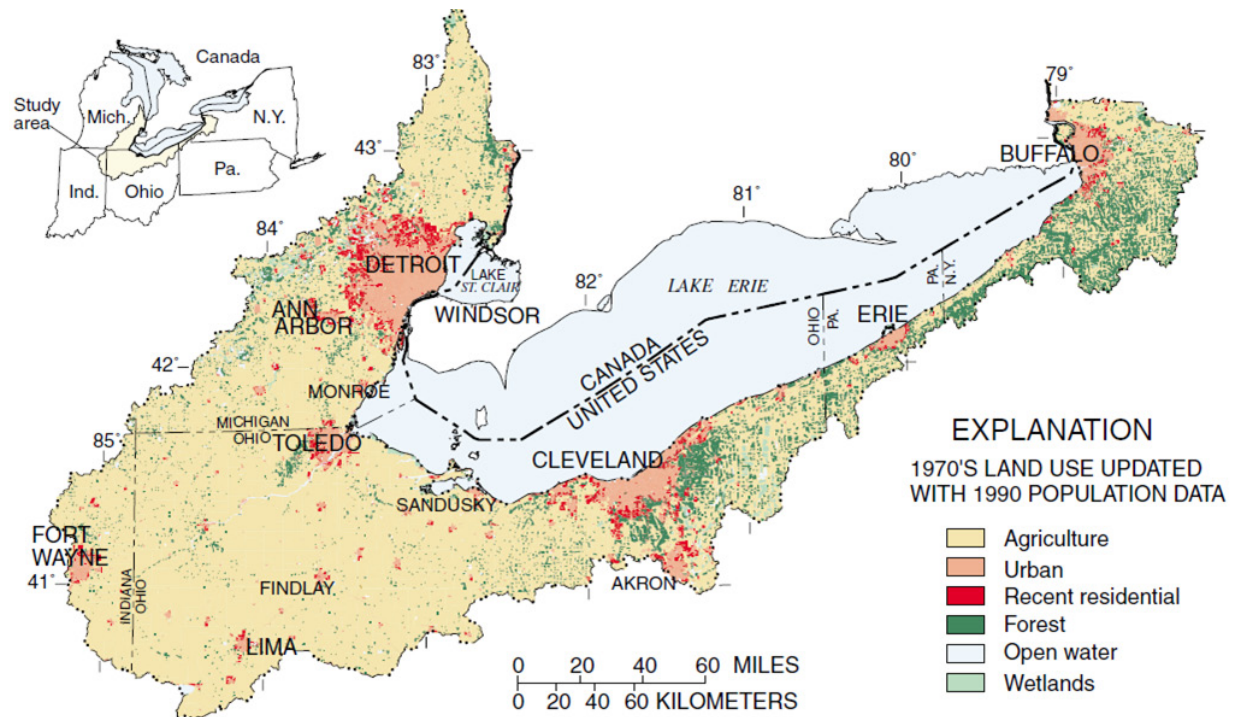
Federal/State Policy

- Coordinate the EPA and Great Lakes states to allow for nutrient Total Maximum Daily Load (TMDL) covering the entire western basin.¹⁶ Potential TMDLs are outlined in a recent report prepared for Ohio Environmental Protection Agency for the Lower Maumee River and Lake Erie.¹⁷
- Establish federal limits on microcystin levels in water used for drinking and swimming to better protect human and wildlife health. The U.S. Environmental Protection Agency can follow limits already established by the World Health Organization.¹⁸
- Fully fund federal investments in the Great Lakes Restoration Initiative (GLRI). Restored wetlands, for example, filter and reduce nutrient loads into the Great Lakes.
- Ensure binational implementation of the 2012 Great Lakes Water Quality Agreement (GLWQA). The GLWQA's Great Lakes Executive Committee (GLEC) should actively coordinate with subcommittees (in this case, the Nutrients and Climate Change subcommittees) to establish specific goals and identify the timeframes and programs needed to achieve these goals.
- Support research on key nutrient sources within watersheds. This will allow for more targeted BMP placement, which will result in more effective adaptive management. Additionally, standardized, regular, and targeted monitoring is needed to effectively protect the nearshore areas of Lake Erie.

INTRODUCTION

Lake Erie is a vital economic, ecological, and recreational resource for millions of residents and visitors alike, and it has the distinction of being the only Great Lake to unite two countries and four states. Home to some of the largest cities in the region, Lake Erie provides drinking water to approximately eleven million residents and generates power for many power plants.¹⁹ The lake supports a \$1.5 billion sport fishing industry and boasts one of the most valuable freshwater commercial fisheries in the world.²⁰

FIGURE 3.
Map of Lake Erie
Drainages
(USGS 2000)



Yet Lake Erie's future remains uncertain due to the proliferation of a single-celled organism: blue-green algae (cyanobacteria), which produce the microcystin toxin. When blue-green algae explode in number, the result is a harmful algal bloom (HAB). HABs, which are linked to levels of phosphorus in Lake Erie, are one of the most significant threats to the lake—and the people and wildlife that rely on it. HABs are particularly prominent in the lake's warm, shallow western basin. Although they are not a new phenomenon in Lake Erie, we are now noticing a striking relationship between large rain events and the size of HABs. Since the late 1990s, heavy precipitation during the early spring and summer months has almost always been followed by copious HAB activity in the late summer and early fall. This calls for more attention to the relationships among phosphorus loading, large rain events, and HABs, particularly as the region experiences less predictable weather and more heavy storms as a result of climate change.

Phosphorus and HABs: The Basics

Algae, particularly green algae, play an essential role in ecosystem health because they form the base of the aquatic food web. These organisms are one of the most basic forms of life, requiring only light, warm temperatures, carbon dioxide, and nutrients to grow. Phosphorus typically serves as the “growth-limiting” nutrient for algal growth because it is present in low concentrations. In larger quantities, however, phosphorus can stimulate excessive growth of algae. While hundreds of beneficial species of algae live in Lake Erie, some, like blue-green algae cyanobacteria, can be hazardous. Excessive phosphorus enables their growth.

HABs emerged as a prominent problem in Lake Erie during the 1960s. The prior decades saw a massive population increase along Lake Erie's shores and, with it, the growth of industries, agriculture, and settlements. These factors contributed to “cultural eutrophication”: increased phosphorus loading from human activities. Some of this

pollution was from “point sources,” so named because its cause was easily identifiable. During this era, municipal treatment plants were the major source of phosphorus. Government action soon followed these then-new and toxic blooms. In 1972, the United States and Canada signed the Great Lakes Water Quality Agreement (GLWQA). This Agreement set target phosphorus load standards for the lake and committed both countries to reduce phosphorus loads, primarily through controls of point sources such as discharges from wastewater treatment plants. Additionally, both the United States and Canada passed legislation and formed new agencies dedicated to administering water quality laws, and revisions of the GLWQA even began to focus on nonpoint source loading. The results were promising: over the next decades, Lake Erie experienced almost a 60 percent reduction in phosphorus loading. Target phosphorus concentrations were reached by the early 1990s, and the benefits were seen in terms of both algae growth and water quality.



Despite these successes, HABs reemerged in the late 1990s as the influence of nonpoint sources, especially within the Maumee River watershed, grew. Myriad factors place the Maumee River at the heart of the problem. The first is location: the Maumee River empties into the waters of Lake Erie’s western basin. The second is volume: the Maumee River is the largest tributary to Lake Erie by area, draining water from four million acres of land. The third is nutrient quantity: the Maumee River is the largest source of DRP flowing into the lake. The fourth is a new ecology: due to invasive mussels the ecological state of Lake Erie changed, giving the phosphorus loads from Maumee River increased influence in supporting HABs.²¹

The effect of phosphorus, particularly from agriculture, is compounded by the lack of forest cover or wetlands acting as buffers against nutrient runoff. These natural features would normally help reduce the quantity of phosphorus-rich fertilizer entering the lake. As of 2009, however, the Lake Erie watershed contained only 54,500 acres of coastal wetland, less than 5 percent of coastal wetlands pre-settlement. This combination of factors has literally proven toxic for the lake.

The Price of HABs: Impacts on Wildlife

Lake Erie is a vital ecosystem that sustains many species of wildlife. The area provides rich food, cover, and nesting habitat necessary to make it a favorite for birds. Some of the species of birds that can be found are American black duck, Harlequin duck, Great Blue Heron, American bald eagle, blue-winged teal, king rail, wood thrust, geese, sandpipers, and the Ohio state bird, the cardinal. Lake Erie’s freshwater fish habitat is well-suited for species like bluegill, walleye, perch, and lake sturgeon. Amphibians and reptiles include the endemic Lake Erie watersnake, Blanding’s turtle, painted turtle, and many species of frogs and toads. Other wildlife species that depend on a healthy Lake Erie include white tail deer, fox, skunk, otters, and beaver.

In large concentrations, all algae carry ecological consequences to Lake Erie, regardless of whether or not they produce toxins. Their decomposition consumes oxygen, leading to hypoxia (reduced dissolved oxygen) in the lake’s bottom waters, which harms fish and other lake organisms and contributes to lake “dead zones.” If overabundance of “harmless” algae is bad, that of HABs is far worse because cyanobacteria may produce microcystin toxins. In Lake Erie, microcystin concentrations have reached extraordinarily high levels in recent years. The World Health Organization limit on microcystin in drinking water is 1 part per billion (ppb); in swimming water, it is 20 ppb.²² Water in Maumee Bay, located in Lake Erie’s western basin, reached 1,200 ppb in 2011.²³



Risk is greatest
when algal blooms
are thickest.
(Ohio Sea Grant and
Stone Laboratory/
Flickr Creative
Commons
September 10, 2009)

This level of toxicity has been found to cause illness and even death in myriad species of fish, birds, and mammals. The toxins affect primarily the liver and disrupt an organism's normal digestion processes. Certain fish species, for example, can experience physical consequences from concentrations as low as a few micrograms per liter (µg/L).²⁴ With the HABs sizes seen in Lake Erie in recent years, fish can be killed in only a few days.²⁵

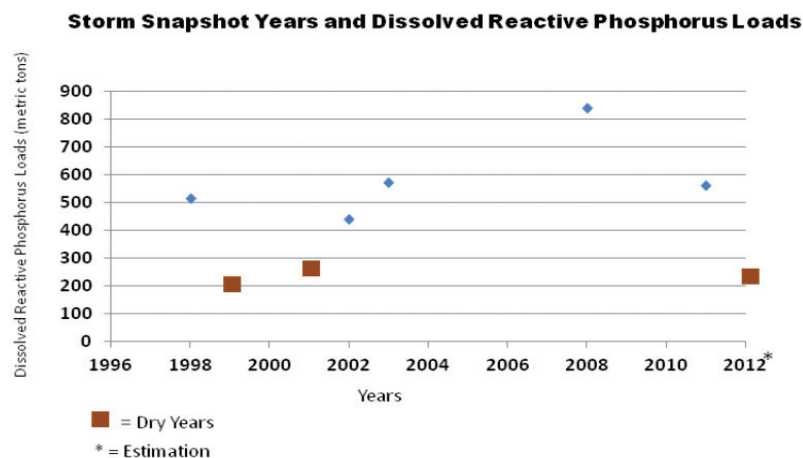
Bird species are also negatively impacted by microcystins, with liver lesions being one significant consequence.²⁶ Waterfowl, which spend a majority of time in the water, are at particular risk. Scientists continue to study the direct effects of microcystins on birds in Lake Erie, but research in other regions speaks to the toxins' capacity to cause significant damage. In the Chesapeake Bay, for example, microcystin poisoning has been linked to mortality and illness of Great Blue Heron; in the Gulf of California, the California Brown Pelican; and in southeastern Florida, the bald eagle.²⁷

In addition to having the potential to diminish Lake Erie's biological diversity, HABs exacerbate the region's economic challenges. As mentioned above, the lake supports a fishing industry that brings in more than \$1 billion per year, and it boasts one of the most valuable freshwater commercial fisheries in the world. Lake Erie is also globally recognized as an important area for birds. Due to Lake Erie's configuration of open water and shoreline, large numbers of varying species of birds migrate through the Maumee Bay area of Lake Erie—in the early spring, as many as one thousand raptors may pass overhead each day. This draws national and international birders in the hundreds of thousands, with more people joining every year. Indeed, in 2011, bird watching was found to contribute more than \$26 million and 283 jobs to northern Ohio's economy.²⁸ In short, Lake Erie's wildlife is vital to both a healthy ecosystem and a strong regional economy, and HABs threaten both.

HABs, Shifting Agricultural Practices, and Large Rain Events

Lake Erie has experienced considerable annual fluctuation in phosphorus loading since the end of the 20th century.²⁹ Increasing number of heavy precipitation events in past decades, combined with shortening fertilizer application windows, appears to have led to increasing soluble phosphorus, or dissolved reactive phosphorus (DRP) loading.³⁰ Resulting DRP numbers have an inextricable link to the size of harmful algal blooms.

FIGURE 4.
Years and Storms
and DRPs

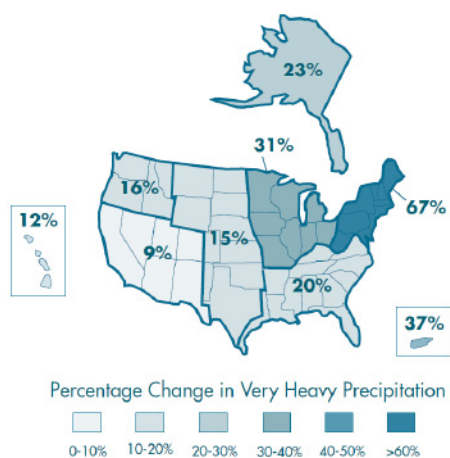


Between 1995 and 2011 observed DRP loads from the Maumee River have increased 218 percent.³¹ It's all about timing. In the past decade, more farmers have begun applying fertilizer after the fall harvest in order to prepare for the following growing season. With no crops to absorb nutrients, the fertilizer is exposed to precipitation. Early spring and summer rains are the greatest contributor of fertilizer into the Maumee River and eventually into Lake Erie. It is therefore no surprise that larger spring

storm events yield greater fertilizer runoff and phosphorus loading in the lake. It is also no surprise that soon after, we see larger HABs. During the typical two-month delay between large spring and summer storms and peak algal biomass, water temperatures warm and sunlight increases, creating better conditions for algal growth. Within Lake Erie, the ideal growth environment for algae is found in the shallow western basin—which is where the Maumee River empties into the lake, and where HABs are most common.

To examine this further, this report offers storm snapshots of eight seasons beginning in 1998 that saw heavy rain events or drought-like conditions in the Maumee River Valley. A season runs from January through June of each year. March to June is a critical period for setting up algal blooms.³² Rain events in this case are considered heavy based upon meteorological standards, significant news coverage, and/or economic losses.³³ Years 1999, 2001, and 2012 are highlighted as contrast cases, during which the Maumee River Valley experienced drought-like conditions, and the resulting HABs were smaller by comparison to rainy years. 2002 is presented as a moderately wet "transition" year to bigger load event years.

FIGURE 5.
Increases in the
Number of Days with
Very Heavy
Precipitation
from 1958 to 2007.
(USGCRP 2009)



higher risk of flood.⁴¹ Rain on snow events⁴² are especially concerning because water runs right off of frozen ground. If rain on snow is coupled with snowmelt, even more water is available for runoff. The wild swings of rain patterns between heavy and light are also expected to continue.⁴³ Experts predict that Ohio will receive less rain in the summer.⁴⁴ The 2013 NCA predicts the number of dry days⁴⁵ to increase in northwestern Ohio.

The season during 2011 presents an alarming storm snapshot of disaster to Lake Erie if record-breaking rains and excess nutrient loads continue. Seventy-five percent of annual normal precipitation fell in the four months between February and May, presenting conditions favorable to an enormous, toxic HAB. How does the storm and bloom of 2011 compare to what we can expect? Scientists recently addressed this question by running climate scenario models to estimate future spring rain event intensity and frequency in the western Lake Erie basin.⁴⁶ These models show that the frequency of events with rainfall amounts greater than 0.7 inches do increase in occurrence; however, larger rain events of rainfall amounts of about 1.2 inches have the potential to be twice as frequent.⁴⁷

Climate changes may also present a need to alter timing of agricultural practices in order to maintain yields. This is primarily because increased precipitation does not necessarily translate into more available moisture for agriculture at the time when the water is needed. Timing and distribution of precipitation will be critical determinants of water availability, and may become increasingly difficult to predict.⁴⁸

A toxic *Microcystis*
bloom washes up on
the shore of Maumee
Bay in western Lake
Erie on August 29, 2011.
(Photo: S. Bihn, Western
Lake Erie Waterkeeper)



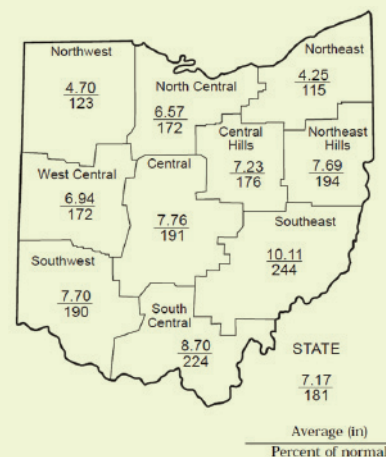
STORM SNAPSHOT 1: 1998's Wet June, Green Lake

In June 1998 precipitation amounts for northwest Ohio were 123 percent of normal.⁴⁹ During this time, the Maumee River Valley experienced a severe storm that resulted in over ten inches of rain, marking the second wettest June for Ohio since 1883.⁵⁰ The flooding caused almost \$180 million in lost and damaged property and took twelve lives.⁵¹ Twenty-three counties in Ohio including Ottawa and Sandusky were declared Federal disaster areas, with more than 100 roads closed and 24,000 people without power.⁵² The Maumee River discharged more than 200 percent of its normal amount for June.⁵³ Between March and June, 171 tons of dissolved reactive phosphorus (DRP) leached into Lake Erie, transported by the Maumee River.⁵⁴ With June as a major contributor, a total of 515 metric tons passed through the Maumee River over the year.⁵⁵ By October, a harmful *Microcystis* bloom was reported in the western basin of Lake Erie. Scientists estimate HAB size as close to the size of 2003's bloom.⁵⁶

Maumee at Waterville 1998 USGS



FIGURE 6.
Ohio Statewide Precipitation Amounts for June 1998



STORM SNAPSHOT 2: 1999's Less Rain, Low DRP

Northwest Ohio and Maumee River Valley stayed dry throughout the spring and summer months of 1999. Beginning in March, the Palmer Drought Severity Index ranking for northwest Ohio was -0.9, indicating incipient drought. Over the next few months it became drier and drier and by June the ranking was -3.4, indicating severe drought.⁵⁷ By July 66 counties in Ohio were receiving federal agricultural disaster declarations for drought, including Maumee River Valley counties such as Williams, Fulton, Henry and Lucas.⁵⁸ According to NOAA's National Climatic Data Center (NCDC) this drought caused \$200 million in crop damages.⁵⁹ From May through October Fulton and Lucas counties received 4-6 inches less than normal precipitation. Ottawa, Wood and Henry counties received 6-8 inches less than normal precipitation.⁶⁰ This year, about 215 metric tons of DRP came through the Maumee River.⁶¹ The size of the bloom was negligible.⁶²

STORM SNAPSHOT 3: 2001 Dry Spring, No Newsworthy Bloom

March 2001 was severely dry in southeast Michigan and northwest Ohio.⁶³ In northwest Ohio precipitation was 28 percent of normal.⁶⁴ By April, Ohio was experiencing the 9th driest year in 119 years.⁶⁵ 2001 did a bit better for pre-

cipitation than 1999, with some heavy rain events in May and the first half of June, but overall it was a dry year. Precipitation statewide remained below normal for the calendar year of 2001.⁶⁶ By the end of the season 260 metric tons of DRP went through the Maumee River.⁶⁷ The size of the bloom was negligible.⁶⁸

STORM SNAPSHOT 4:

2002 Swings of Wet and Dry, the Bloom Didn't Lie

Warm wintertime temperatures caused precipitation in February and March to fall as both rain and snow, causing rain-on-snow events.⁶⁹ Minor flooding was reported in February for northern Ohio.⁷⁰ Spring experienced flooding, with rainfall amounts in March, April, and May over 100 percent of normal.⁷¹ Most of the precipitation over northwestern Ohio in March, however, fell as snow so the runoff conditions were less in comparison to April and May. By April, discharge for Maumee River at Waterville was 140 percent of normal and 192 percent of normal in May.⁷² Very dry conditions started in June, with rainfall amounts dipping to 53 percent of normal, and lasted for the rest of the summer. Discharge for Maumee River at Waterville declined to 61 percent of normal.⁷³ The winter and spring rains were enough to flush 440 metric tons of DRP through the Maumee River.⁷⁴ The resulting bloom was about 65 square miles.⁷⁵

STORM SNAPSHOT 5:

2003 Rain Rain, Won't Go Away

In the late spring and summer of 2003 Ohio was experiencing the wettest conditions in the country. In fact, northern Ohio was hit with its third-wettest May in over one hundred years.⁷⁶ Every week brought a new storm. Lake Erie rose more than four inches as a result of precipitation across the Upper Great Lakes, and the Maumee River discharged 359 percent of its average monthly discharge.⁷⁷ Many fields in the region were damaged from the flooding, and whatever fertilizer had been applied washed into the lake. Between March and June, a total of 322 tons of DRP were deposited into the western basin.⁷⁸ Several large storms also occurred in July and August. These months went on record as one of the wettest May-August periods ever experienced in Ohio.⁷⁹ May discharge through Maumee River at Waterville was 359 percent of normal.⁸⁰ By the end of the season 570 metric tons of DRP went through the Maumee River.⁸¹ The fall of 2003 brought with it a massive algal bloom. Because large storms occurred as late as August, the bloom lasted longer than usual. In early September the bloom was mostly confined to the western basin. However, by November, the bloom had spread into the central basin of the lake. At its peak the harmful bloom covered 272 square miles.⁸² 2003 was also the first year cameras on NASA satellites captured the above-earth view of green HABs.⁸³ Seeing HABs from space illustrated the problem for the public in a whole new way.

FIGURE 7.

(Top) Lake Erie September 6, 2003 (MODIS Aqua NASA Visible Earth)
(Bottom) Lake Erie November 20, 2003 (MODIS Aqua NASA Visible Earth)

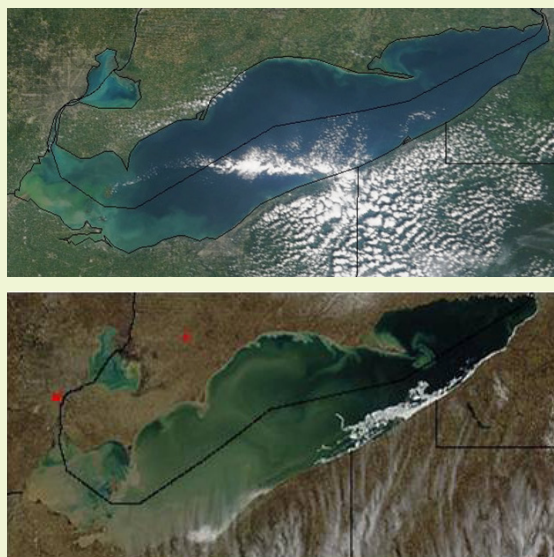
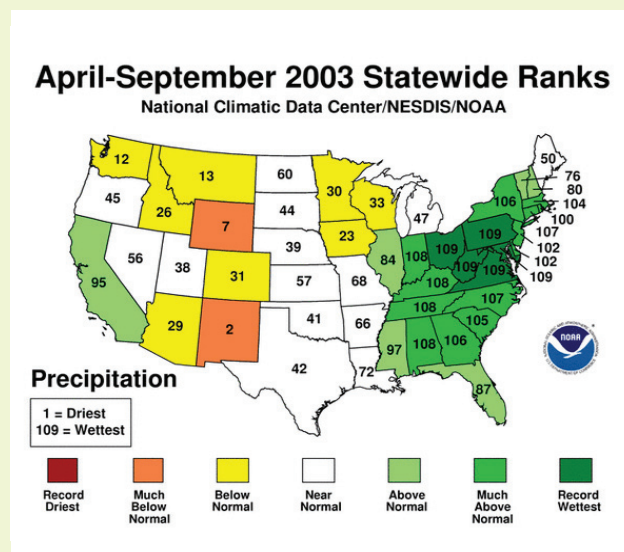


FIGURE 8.

National Ranks of Precipitation from April through September 2003. Ohio ranks among the wettest in the country. (NCDC NOAA 2012)



STORM SNAPSHOT 6: 2008 Record Breaking, Lake Loading

The first half of 2008 was the second wettest on record for Ohio.⁸⁴ Flooding caused extensive damage to fields and interfered with spring planting.⁸⁵ In June, massive flooding occurred throughout the Midwest, and over 1100 daily precipitation records were broken throughout the region.⁸⁶ Over northwest Ohio precipitation amounts were 151 percent of normal.⁸⁷ The Maumee River Basin received approximately 8 inches of rain during the month of June alone.⁸⁸ The discharge for Maumee River at Waterville in June was 199 percent of normal.⁸⁹ As a result, 265 tons of DRP entered Lake Erie.⁹⁰ Short heavy rain events defined the rest of the season. Over the July 4th holiday, for example, a storm over northwest Ohio presented 3 inches of rain.⁹¹ Precipitation amounts remained above normal statewide for the entire year.⁹² By the end of the season 840 metric tons of DRP went through the Maumee River.⁹³ The consequence was a harmful algal bloom that spanned over 400 square miles.⁹⁴

STORM SNAPSHOT 7: 2011 New Decade, Decadal-Sized Blooms

Between 2009 and 2011, Lake Erie experienced heavy blooms every year.⁹⁵ The year 2011 was particularly exceptional and is considered by scientists to be the worst bloom that Lake Erie has seen in decades.⁹⁶ These years provided a perfect storm of sorts. First, fertilizer sales in 2010 were Ohio's highest in a decade, and the fall of 2010 presented relatively dry conditions which presented an ideal opportunity for fall fertilizer application and field preparation.⁹⁷ Then, the spring of 2011 was the wettest Ohio has ever experienced.⁹⁸ Several locations received 75 percent of their normal annual precipitation in the four-month span between February and May.⁹⁹ In northwest Ohio rainfall exceeded normal precipitation by 195 percent in April and by May, 232 percent of normal.¹⁰⁰ Meteorologist Marty Thompson with the Cleveland National Weather Service Forecast Office said in May, "Everybody's talking about it because it seems like it's raining every day."¹⁰¹

FIGURE 10.
Lake Erie October 9, 2011 (Earth Observatory NASA)



FIGURE 9.
National Ranks of Precipitation from April through September 2008. Ohio ranks among the wettest in the country. (NCDC NOAA 2012)

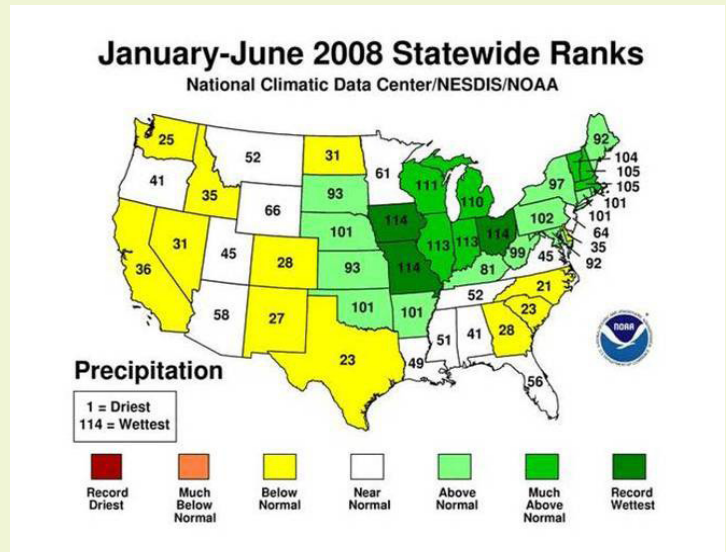


FIGURE 11.
Wake following a small boat on Lake Erie in July 2011 (NOAA/NCCOS)



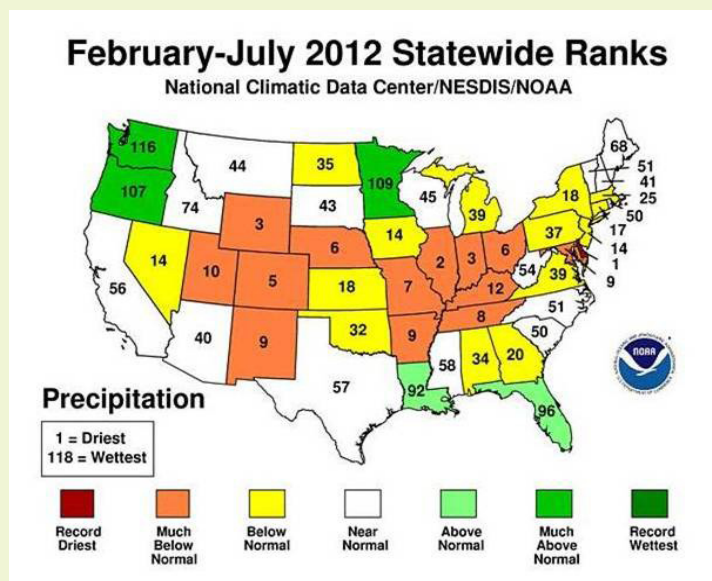
The storms of 2011 were heavy. Almost continuous severe thunderstorms pelted Ohio in May of 2011, resulting in significant flooding.¹⁰² According to the USGS Water-Data Report, the Maumee River discharged a high daily mean of 78,000 cubic feet per second (CFS) in May, more than 500 percent of normal flow.¹⁰³ This emptied more than 400 tons of DRP into the western basin.¹⁰⁴ This storm represents the 99.8th percentile for Maumee daily discharge since 1975.¹⁰⁵ Additionally Lake Erie experienced weak circulation and current from February through July.¹⁰⁶ This reduced mixing in the western basin, which decreased dilution of the Maumee's nutrient-rich waters. All of this water combined with heavy nutrient application led to high DRP loads and huge blooms. By the end of the season 560 metric tons of DRP went through the Maumee River.¹⁰⁷ The resultant bloom was massive, covering more than 3,000 square miles by early October.¹⁰⁸ Scientists have recently concluded that all of the factors leading to the 2011 bloom will likely reappear in the future.¹⁰⁹ Climate scenario models show that larger storm events of 1.2 inches or higher falling over western Lake Erie basin could be twice as frequent.¹¹⁰

STORM SNAPSHOT 8: 2012 Drier Year, Smaller Bloom

Compared to previous years, the year 2012 was a relief for Lake Erie's health. Drought coupled with few large rain events yielded a mild year for HABs. According to the Palmer Drought Severity Index, the Maumee Bay watershed experienced Moderate drought for part of the spring and Severe-to-Extreme drought all summer.¹¹¹ The lack of spring storms greatly reduced runoff between March and June, resulting in less phosphorus entering Lake Erie.¹¹² A study by Heidelberg University shows that the amount of phosphorous that entered the lake during the April-through-June period was about 2.5 percent of 2011's amount for the same period.¹¹³ However, lack of rain taxed water systems and presented major challenges for the region's agriculture sector. Scientists are currently working on estimating and reporting the total size of the bloom.

FIGURE 12.

National Ranks of Precipitation from February through July 2012. Ohio ranks among the driest in the country. (NCDC NOAA 2012)



CONCLUSION & RECOMMENDATIONS

Climate change is causing warmer air temperatures and altering rain patterns over the Maumee River Valley in profound ways. These rain patterns, combined with other factors, are contributing to nutrient runoff and harmful algal blooms in Lake Erie. Lake Erie's water quality is compromised and thus impacts the health of the people and wildlife. Without serious action on curbing greenhouse gas pollution—as, unfortunately, is the case currently—we will continue to experience warmer air temperatures and the intense weather events that occur as a result. Therefore we should prepare for these changes to protect the health of Lake Erie's human and wildlife populations from toxic algal blooms.



In the past, we have had considerable success in regulating point source pollution. There is potential to achieve similar levels of success with nonpoint source pollution if policies, land management practices, and research and monitoring initiatives are supported and implemented effectively. More innovative policies, updated best management practices, combined with additional outreach and understanding, will create solutions that help ensure that heavy storms do not exacerbate Lake Erie's existing vulnerability to phosphorus loading and Harmful Algal Blooms. **By working together as a public along with scientists, weather and climate forecasters, policy makers, nonprofits, federal and state agencies, farmers, businesses, and land managers, we can protect this treasured Lake Erie ecosystem.** Next are several principal recommendations, accounting for this range of sectors and stakeholders, to reduce the consequences of heavy storms on HAB growth in Lake Erie.

RECOMMENDATIONS

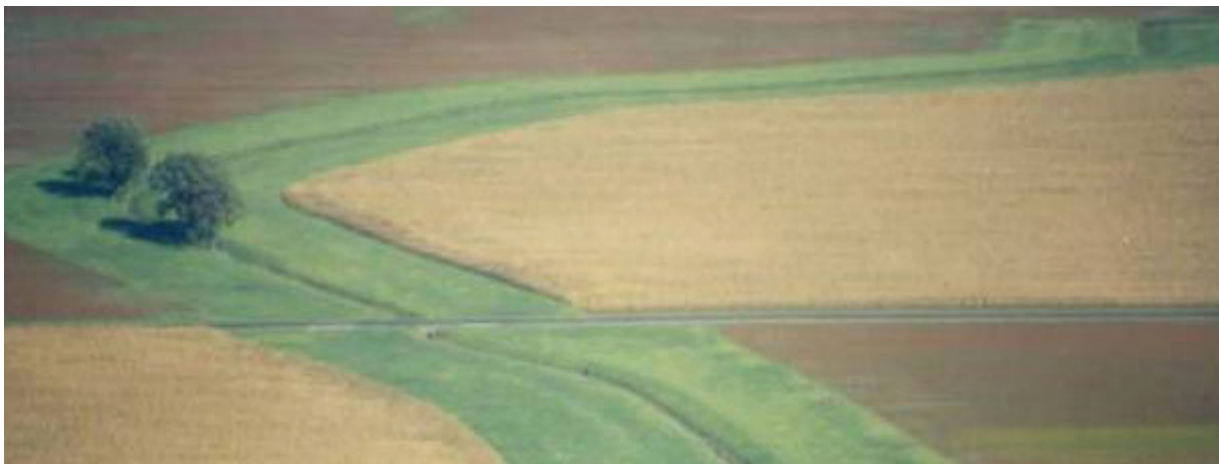
Accounting for Climate Change in Land Management

While farmers and land managers have a deep understanding of the weather, it would be helpful for them to have the tools and knowledge to better predict what may happen in the future with climate change to adequately prepare land practices for change.

- Farmers, land managers, and Certified Crop Advisors (CCAs) should develop partnerships with respective state climatologists and/or the Great Lakes Integrated Sciences and Assessment Center (GLISA).¹¹⁴ These scientists have access to decades of historical records and the climate model expertise to give seasonal or longer-term rainfall forecasts, useful for adjusting nutrient application practices and/or making conservation wetland decisions.
- The National Weather Service's National Climate Prediction Center should issue a public warning for seasons with high runoff potential (i.e. heavier rain seasons).
- United States Department of Agriculture Natural Resource Conservation Service (NRCS) should prioritize, incentivize, and fund land buffer enhancements for the Maumee River watershed. This land could act as a buffer for nutrients during heavy rains.

Nutrient Management Practices for Agriculture

Agriculture is the biggest contributor of excess phosphorus loading in Lake Erie. Consequently, efforts to decrease loading must focus on the magnitude and timing of the application of fertilizer to farmland. Considerable efforts have already been made to reduce phosphorus and sediment loads, but even further reductions are necessary given the heavier storms and greater rainfall occurring in this region. Since we cannot do anything in the short-term about large storms, our only option is to keep phosphorus runoff to a minimum.



- Identify Best Management Practices (BMPs) that fit climate and weather trends by reducing phosphorus levels on the soil surface. Until recently conservation tillage was thought to be a standard best management practice as it has great benefits toward preventing erosion. However, heavy fertilizer application combined with conservation practices leave high concentrations of phosphorus from fertilizer on the upper soil, leaving concentrations susceptible to wash into lakes and streams with rain runoff.¹¹⁵ Weather might matter less if the farmers reduce the practice of conservation tillage alongside heavy fertilizer application, or take extra steps to ensure that fertilizer gets below the surface to avoid losses through tiles. A promising BMP approach that accounts for heavier rain is the use of cover crops¹¹⁶, as they diminish nutrient reduction from runoff and reduce overall erosion by keeping soils covered.¹¹⁷ With no changes in agriculture practices, warmer weather and increased frequency of severe storms could increase negative impacts of existing practices.¹¹⁸
- Streamline enforcement of BMPs, especially those that are effective under heavy rain scenarios. Agencies like the Ohio Department of Natural Resources could lead the way.
- Consider timing of nutrient application. Do not apply nutrient fertilizers if the weather forecast calls for a greater than 50 percent chance of heavy rain. Avoid application on frozen ground.
- Create a mechanism for ongoing, formal public review of the efficacy of management efforts. Even though we can still expect wild swings in precipitation amounts—placing some years in drought conditions—we must continue to update our efforts on preventing large amounts of runoff, learning from on-the-ground practices and the best available science.

State Policies and Laws

Policies that protect Lake Erie must be reviewed and updated to ensure that their original intention is carried through. State laws are important, as they are primarily responsible for regulating nonpoint source pollution.

- The Ohio Department of Natural Resources should designate the Lake Erie watershed as being “in distress.” This designation would trigger new regulations restricting manure application on frozen ground and mandating conformation to state-approved nutrient management plans.¹¹⁹
- Ohio must require National Pollution Discharge Elimination System (NPDES) permits to contain limits on nonpoint sources of phosphorus in order to comply with the state’s water quality standards. Only a small percentage of Ohio NPDES permits in the Lake Erie basin contain limits on nonpoint sources of phosphorus, and most permits do not even require monitoring.¹²⁰
- The Ohio Environmental Protection Agency (OEPA) should require innovative, environmentally friendly ways to combat runoff via “green infrastructure.” For example, OEPA could require permeable pavement or grassed swales¹²¹ in NPDES permitting to reduce phosphorus runoff.
- Prohibit excessive water withdrawals from sensitive rivers and streams within Lake Erie’s watershed by complying with the Great Lakes Compact. Excessive water withdrawals from tributaries could result in reduced water flows and oxygen levels, and add further stress to Lake Erie.

Federal Clean Water Act

Enhance regulation standards under the Clean Water Act (CWA) to aggressively target phosphorus. This federal legislation, enacted in 1972, is designed to regulate discharge of pollutants through a state permitting process. There are several ways in which its impact could be strengthened.



- Regulate stormwater runoff from agricultural lands as a point source. Although certain types of stormwater are regulated as point sources (e.g., municipal, construction), most storm runoff is classified as nonpoint source pollution. In general, the CWA has been more successful in reducing pollution from point sources than from nonpoint sources.¹²²
- For further reduction of nonpoint source pollution, fully fund and implement CWA's Section 319 programs, as these programs provide necessary assistance to states, territories and tribal nations that help enhance water quality.
- Follow the United States Environmental Protection Agency's recent guidance on key components of an effective state nonpoint source management program¹²³. Posted in November 2012, this guidance reviews and updates components of nonpoint source management set in 1997.¹²⁴
- On a state specific scale, Ohio should abide by the recommendations laid out by a recent report published for the Ohio EPA. This report outlines potential Total Maximum Daily Load (TMDL)¹²⁵ standards for nutrients in the Lower Maumee River and Lake Erie.¹²⁶ In the meantime, other Great Lakes states should revisit and revise existing criteria.
- The U.S. EPA should play a more active role in coordinating Great Lakes state TMDLs for nutrients. TMDL consistency among states will advance the ultimate objectives of reducing nutrient loading. Achieving a goal of consistency depends upon coordination among the states, something that the EPA can help facilitate.

Federal Agriculture Programs

Sustain programs within the Natural Resources Conservation Service (NRCS) of the US Department of Agriculture that provide technical and financial assistance to landowners for conservation planning and Best Management Practice (BMP) implementation.

- Maintain declaration of the Maumee River watershed as an area of "extreme ecological sensitivity."¹²⁷
- Provide more oversight of agricultural operations participating in Farm Bill programs and recommend wider buffer zones between all row crops and surface waters.
- Promote the 4R's of nutrient stewardship: Right fertilizer source at the Right rate, at the Right time and in the Right place. Learn more at The 4R Nutrient Stewardship Portal: <http://www.ipni.net/4R>
- Prioritize and implement key recommendations of the Great Lakes Commission Phosphorus Reduction Task Force. The Task Force recently identified technical assistance as a potentially limiting factor in the implementation of conservation programs. To improve the effectiveness of these programs, NRCS should work with the Great Lakes states to ensure all areas receive sufficient technical assistance.¹²⁸
- Congress must pass a five-year Farm Bill with a strong conservation title that includes the Regional Conservation Partnership Program that could directly benefit the Great Lakes. This program would significantly enhance conservation, restoration, and sustainable use of soil, water, wildlife, and other natural resources in the Great Lakes region.
 - > In addition, Congress must pass a Farm Bill that re-links conservation compliance to crop insurance. Conservation compliance is a compact between farmers and taxpayers that states that in return for receiving federal subsidies, farmers should meet some basic eligibility requirements: they must refrain from farming highly erodible soils without a conservation plan or draining wetlands on their property.

Federal Great Lakes Restoration Initiative (GLRI)

The President and Congress should fully support the Great Lakes Restoration Initiative (GLRI), which provides critical funding to restore the Great Lakes ecosystem. Restoration of Maumee Bay wetlands, for example, provide a filter that can reduce the quantity of nutrients that reach Lake Erie.

- Appropriate GLRI funds included in the President's budget.
- Provide grants for large-scale watershed projects capable of achieving considerable reductions in phosphorus loadings. In high-priority watersheds, it may be beneficial to support fewer but larger-scale nutrient reduction projects.¹²⁹
- Support improvement of watershed and lake models to refine target loads, and monitoring and assessment to track progress.

International Bodies and Agreements

Reduce nutrient loading by implementing Great Lakes water quality agreements and prioritizing Lake Erie on the international level, e.g. through the International Joint Commission.

- Improve multinational coordination between the U.S., Canada, and tribal nations regarding Lake Erie's ecosystem health. Moving in the right direction, the International Joint Commission (IJC) recently announced it has made the Lake Erie Ecosystem a priority for 2012 through 2015.¹³⁰ Through the Lake Erie Ecosystem Priority, the Commission aims to develop recommendations for better monitoring systems and best management practices to handle agricultural, urban and industrial sources of nutrient pollution.¹³¹
- Implement the recent revision of the Great Lakes Water Quality Agreement (GLWQA). The 2012 amendment addresses the phosphorus-loading problem in all five lakes and calls for updated phosphorus load targets. The revision also sets out a framework calling for adoption of new objectives and strategies, as well as an implementation plan for the next several years. Updated phosphorus targets must be calculated using the best available science. Target levels of phosphorus should be established for distinct lake regions, and scientific models should be used to calculate load reductions required to meet in-lake targets.¹³²
 - > The GLWQA's Great Lakes Executive Committee (GLEC) should actively coordinate with public subcommittees (in this case, the Nutrients subcommittee) to establish specific goals and identify the timeframes and programs needed to achieve these goals.

Research

Continue research on key nutrient sources within watersheds. This will allow for more targeted BMP placement, which will result in more effective management. Several academic institutions and private companies have undertaken this work in the past, but it is a constantly evolving issue requiring continued effort.

- Improve climate modeling capabilities in the basin, considering variability in precipitation patterns due to climate change.
- Support ongoing research on the ecological impacts of HABs in Lake Erie, specifically on wildlife.
- Follow the recommendations of further research from the Great Lakes Commission Phosphorus Reduction Task Force. These include:
 - > A phosphorus transport model which incorporates DRP and subsurface drainages
 - > A phosphorus mass-balance study for each lake and sub-basins
 - > Updated soil testing methodologies in view of continuing climate change and current or shifting farming practices
 - > New technologies, management practices, and methodologies to reduce phosphorus discharges from permitted facilities.
- Establish a regulatory authority to utilize research more efficiently within Great Lakes states. This would include designating high-priority watersheds and initiating mandatory actions to reduce loadings. Wisconsin is a good model for other states, especially in terms of the phosphorus rules.¹³³

Reduce carbon pollution

Reduce carbon pollution and restore our natural systems that absorb carbon from the atmosphere. This will help prevent future warming and thus heavy storms.

- Use and protect the laws we have to limit carbon pollution from major air pollution sources like coal-fired power plants, oil refineries, and cars.
- Prioritize energy policies that support a rapid transition away from fossil fuels and advance the renewable energy sources needed to build a clean energy economy.

Monitoring

Standardized, regular, and targeted monitoring is needed in the nearshore areas of Lake Erie. Nearshore areas are especially important since *Microcystis* blooms are harmful to humans and wildlife.

- Support and fund the Coordinated Science and Monitoring Initiative¹³⁴—a binational initiative to help integrate and coordinate monitoring efforts.
- OEPA should require more NPDES permit holders in the Lake Erie basin to monitor for phosphorus.
- Increase effort to integrate the results of research and monitoring into development and implementation of policy.

Public Watch and Education

The public should continue to stay updated on harmful algal blooms, especially in seasons of heavy rainfall.

- Promote the EPA Urban Water Resources and Pollution Prevention website, a source of education about the issue and ways to contribute to a solution: <http://www.epa.gov/urbanwaters/resources.html>.
- Obtain current and/or archived data on Lake Erie's HABs through NOAA's Experimental HAB Bulletin website: http://www.glerl.noaa.gov/res/Centers/HABS/lake_erie_hab/lake_erie_hab.html.
- Stay up-to-date with real-time flood and storm information, including flash flood data obtained from river gauges, on NOAA's Automated Flood Warning Systems website: <http://afws.erh.noaa.gov/afws/national.php>.



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Ducks in wetland.
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